

Cryogenic Filters for RFI Protection

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The increased bandwidth and sensitivity of the DSN maser-based receiver systems along with the increase in worldwide microwave spectrum usage have dictated the need for employing additional measures to protect these systems from RFI (radio frequency interference). Both in-band and out-of-band microwave signals at the input of the Deep Space Network (DSN) traveling wave masers (TWM) can adversely affect the maser performance in a variety of ways. Filters fabricated from superconducting materials operating below their superconducting transition temperature (T_c) possess the most potential for providing the necessary RFI protection without degrading the system performance.

I. Introduction

To meet the increased demands of more challenging space-craft missions and at the same time provide for more deep space station users such as Very Long Baseline Interferometry (VLBI) and Radio Frequency Interference (RFI) Surveillance, the bandwidth as well as the sensitivity of present masers have been increased over previous designs (Ref. 1). Unfortunately, this increase in performance and versatility has also yielded a greater maser susceptibility to RFI.

The effect of RFI on the maser performance is primarily determined by the level of the RFI, its frequency and how its frequency relates with the frequency of the maser pump source(s). Both in-band and out-of-band RFI (CW and pulse) can result in either gain loss or spurious output signals or both in the maser signal bandpass (Ref. 2).

The long-term goal of the Cryogenic Filter Project at JPL is the development and testing of cryogenically cooled filters which will protect the DSN S-band and X-band masers from

in-band and out-of-band RFI without degrading the maser sensitivity, amplitude, phase, or group delay stability, or adding dispersion within the bandpass. The project has been divided into the following six sequential steps:

- (1) Measure the effects of CW and pulse RFI on the Block II X-band TWM.
- (2) Research the probable levels and frequencies of known sources of RFI.
- (3) Develop a fixed, cryogenically cooled filter to protect the Block II X-band TWM from out-of-band RFI.
- (4) Measure the effects of CW and pulse RFI on the Block III/IV S-band TWM.
- (5) Develop a fixed cryogenically cooled filter to protect the Block III/IV S-band TWM's from out-of-band RFI.
- (6) Develop a variable-frequency cryogenic filter which can provide protection from in-band RFI for the above TWM's.

This introductory report will discuss the susceptibility of the Block II TWM (Ref. 3) to out-of-band RFI and the design approaches being investigated for the fixed, cryogenically cooled filter for this TWM.

II. Block II X-Band Maser Susceptibility to CW RFI

A. Maser Gain Reduction

In general, from 7 GHz to at least 40 GHz (our upper limit of measurement) levels greater than 0 dBm can cause measurable maser gain reduction (greater than 0.1 dB) in the maser passband. In addition to the above general susceptibility, there are three RFI frequency bands (7.6-9.1, 15.3-15.9 and 34.3-35.5 GHz) where levels below 0 dBm will reduce the maser gain. The minimum RFI power level in each of these frequency bands which results in a 1-dB maser gain reduction in the signal passband (8.4-8.5 GHz) is shown in Fig. 1. RFI at these frequencies induces transitions between the paramagnetic energy states, resulting in a gain loss due to the degradation of the inverted population condition.

B. Mixing Effects

At the idler frequencies, masers are particularly sensitive to RFI. An idler frequency f_i is defined according to the following equation $f_i = f_p - f_s$, where f_p is a maser pump frequency (or sum of pump frequencies) and f_s is the signal frequency (Ref. 4). The Block II X-band TWM has three idler frequency ranges which are listed in Table 1.

An RFI signal at any one of these idler frequencies can mix with the maser pump energy, resulting in an output in the operating maser passband (8400-8500 MHz). (It should be noted that the 4th, 5th and 17th transmitter harmonics of the DSN S-band transmitters occur in the X-band TWM passband and very near two of the three idler frequency bands (Ref. 5).) Since the pump source is composed of two free-running gunn oscillators that are frequency-modulated at the rate of 100 kHz, the mixed output will also be modulated at the same rate and might appear as broadband noise on a spectrum analyzer. This mixing will occur with a conversion loss of 90 dBm minimum when referenced to the maser input (Ref. 2). For example, a -60 dBm signal at 10.76 GHz mixed with the 19.2 GHz pump source results in a -150 dBm maximum signal at 8.44 GHz. After amplification by the maser (45 dB nominal) the final output is an FM-modulated (100 kHz) signal at 8.44 GHz with signal level of -105 dBm maximum.

Although the mixing discussed above is strictly a function of the electron spin resonances of the maser active material, nonlinear components in the maser such as metal-oxide-metal

junctions and YIG isolators can also cause mixing with the maser pump frequencies. The conversion losses for these processes are expected to be much higher than those due to electron spin resonances.

Measurement of these mixing effects in a Block II X-band maser is presently underway.

III. Filter Design Goals

In view of the variety of ways in which out-of-band RFI can adversely affect maser performance, a filter is needed which precedes the input of the maser amplifier to provide adequate protection from these interferences. Using Fig. 1, the results of Section II, known characteristics of the Block II TWM and practical design considerations, a fixed bandpass preselector is proposed for the X-band Block II TWM. We present the insertion loss and rejection design goals for this filter in Fig. 2. The response limits are contained within the shaded region of this figure.

The proposed filter is designed to adhere to the following guidelines and requirements:

- (1) An insertion loss of no greater than 0.1 dB at the bandpass is necessary so that when the filter is cooled down to 4.5 K the filter noise temperature contribution is below 0.2 K.
- (2) The rejection characteristics surrounding the maser operating passband must be as steep as possible without adding significant dispersion within the passband.
- (3) A 50-dB rejection "floor" from 0-10 GHz gives more than adequate protection in this frequency range ($\gg 0$ dBm RFI) and is easily realizable.
- (4) An increased rejection of 100 dB from 10-40 GHz is needed to provide protection from RFI in the idler frequency bands. 100-dB rejection will insure that idler band power levels of less than 0 dBm will result in spurious maser output levels less than the minimum detectable signal level.

IV. Approach

Because of the low loss characteristics of superconductors operating below T_c , their critical temperature, it has been suggested and demonstrated that filters fabricated from these materials would in principle have the ideal characteristics for our applications. In fact, the only known way of obtaining a filter insertion loss of 0.1 dB is by using superconducting

materials because of their extremely low surface impedance when cooled below T_c .

The surface impedances of some superconductors have values 5 to 6 orders of magnitude smaller than the best normal conductors at 1-7 GHz (Refs. 6, 7). In addition, certain A15 compounds like NbTi, Nb₃ and Nb₃Sn possess relatively high T_c 's (9.5, 9.2, and 18.0 K) and relatively good mechanical properties, allowing repeated thermal cycling without any deleterious effects (Ref. 8). Depending on physical size constraints and engineering difficulties, such filters could be microstrip, air line or cavity construction.

For example, where size is a major constraint and/or frequency ranges dictate smaller dimensions, microstrip filters could be fabricated from Nb or Nb₃Sn, utilizing thin film deposition techniques. The thin films would be deposited by either magnetron sputtering or electron-beam evaporation techniques onto a sapphire substrate. This latter process is still under development and Stanford University (in collaboration with JPL) has started a program to evaluate the RF characteristics of such structures.

For masers with less stringent physical constraints and/or higher frequencies, filters could be fabricated from bulk superconductors like NbTi. Currently, we are evaluating the performance of several interdigital X-band filters machined from NbTi. The preliminary results from these tests are very encouraging and will be reported in a future article. This is the approach that has been chosen for the Block II X-band fixed filter.

V. Plans

Our plans are to develop, test and build a prototype fixed X-band filter for implementation in the X-band Block II-A TWM by the middle of 1982. The prototype fixed S-band filter will be ready for implementation in the Block III and IV S-band masers by early 1983.

In FY 1983 work will begin on tunable cryogenic filters which will protect the maser receiver system from in-band RFI.

References

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Table 1. Summary of RFI susceptibility: X-band Block II TWM

Signal frequency range	8.40 – 8.50 GHz
Maser net gain	46 dB max 43 dB min
Signal power input level for –1 dB gain compression	–84 dBm
Pump source frequency range ^a (Low-frequency (3-4) pump; includes FM modulation)	19.11 – 19.32 GHz
Pump source frequency range ^a (High-frequency (1-3) pump; includes FM modulation)	23.91 – 24.25 GHz
Idler frequency ranges	
$f_{p_{3-4}} - f_s$	10.61 – 10.92 GHz
$f_{p_{1-3}} - f_s$	15.41 – 15.75 GHz
$f_{p_{1-3}} + f_{p_{3-4}} - f_s$	34.53 – 35.18 GHz
Mixing possibilities due to nonlinearities in maser structure	
$f_{p_{3-4}} + f_s$	27.51 – 27.82 GHz
$f_{p_{1-3}} + f_s$	32.31 – 32.75 GHz
Maser gain compression due to out-of-band RFI	See Fig. 1
^a These are the minimum and maximum pump frequencies observed on six operating masers.	

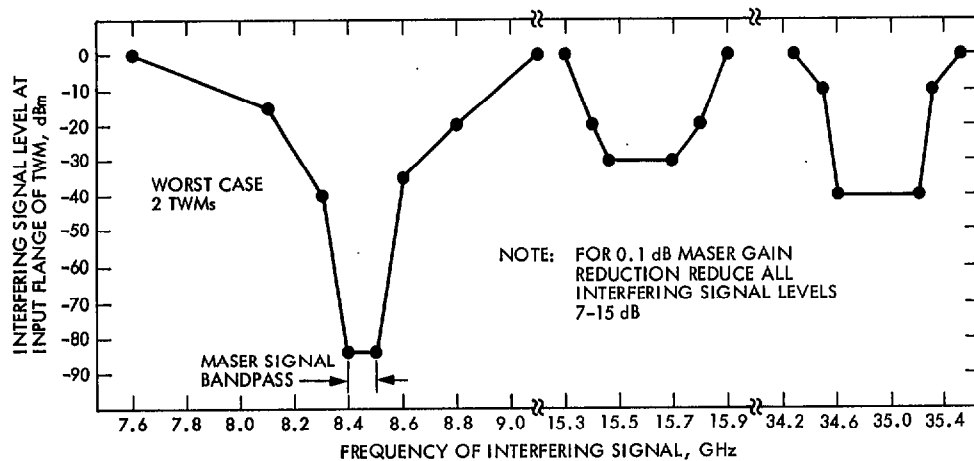


Fig. 1. Plot of the signal level required to reduce maser gain 1.0 dB as measured at 8.4–8.5 GHz (X-band Block II TWM)

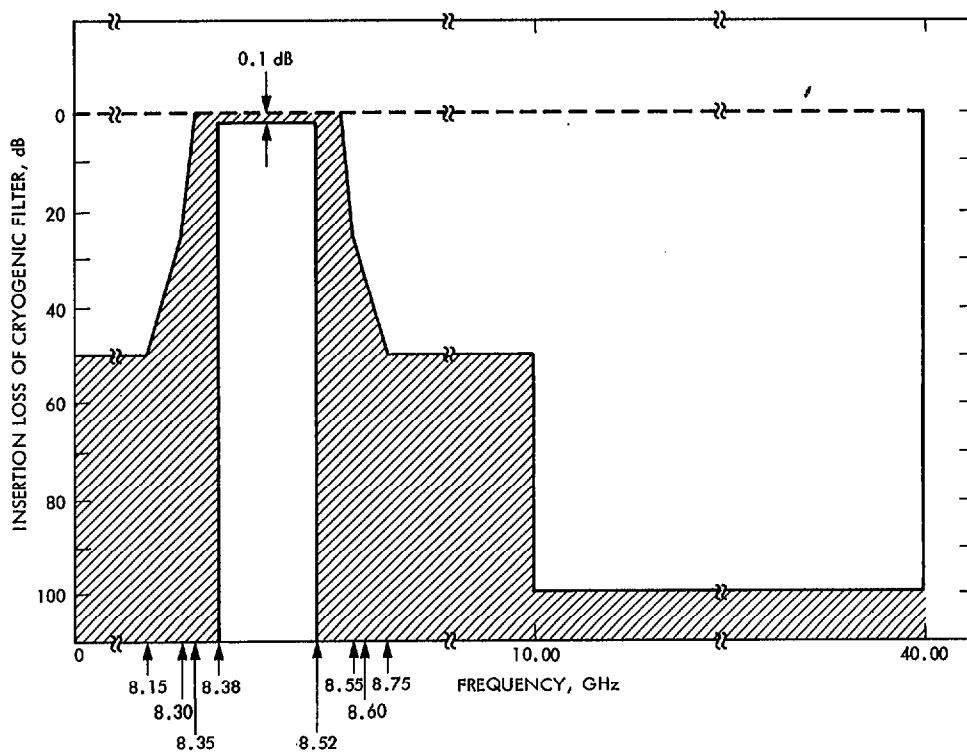


Fig. 2. Plot of the design goals for a cryogenic low loss input filter (X-band Block II TWM)